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Index Terms:
Europe GSM cellular radio environments RF link aeronautical transponder aircraft communication capacity estimates cellular radio feasibility study group special mobiles handover network organisation passenger aircraft radiotelephony signalling system architecture transmission delay compensation transponders Europe GSM cellular radio environments RF link aeronautical transponder aircraft communication capacity estimates cellular radio feasibility study group special mobiles handover network organisation passenger aircraft radiotelephony signalling system architecture transmission delay compensation transponders

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THE PROVISION OF GSM CELLULAR RADIO ENVIRONMENTS WITHIN PASSENGER AIRCRAFT OPERATING OVER EUROPE

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ABSTRACT

The paper reports the findings of a feasibility study into the means of provision of a GSM cellular radio environment inside passenger aircraft. The background and capacity estimates for such a system are discussed prior to the presentation of a description of proposed system architecture. This description includes topics such as Network organisation, Handover, Transmission delay compensation, Signalling, the RF link and the Aeronautical Transponder implementation.

1. INTRODUCTION

The objective of this paper is to provide an overview of the findings of a feasibility study carried out for the United Kingdom Department of Trade and Industry by Racal Research Limited and their consultants. The study was one of two which addressed separate aspects of the provision of a GSM microcell within a civil aircraft operating over Europe. The Racal study addressed all aspects, other than the topics of propagation and EMC effects within the aircraft and the difficult problem of interference between the aircraft microcell and the conventional ground based GSM network. The latter was carried out under a separate contract by GEC Marconi Research Limited.

It is not possible to provide much more than a high level overview of work carried out during the six month study in a single paper. Hence, the main body of the paper (section 4) will consist of a description of the chosen solution. To provide the necessary context, section 4 will be preceded by a brief review of the relevant background and a short section discussing the selection of the backhaul link from the aircraft to the ground.

2. BACKGROUND

By the mid-1990s, it is anticipated that some 4 million GSM hand-portable telephones will be in use throughout the major population centres of Western Europe. Many of their owners will frequently travel by air and will wish to make use of their hand-portable not only while at their destination but whilst in flight, en-route for their destination. This reasonable expectation will be further reinforced in the minds of those who make international flights which by then are expected to provide passenger telephone facilities by means of the INMARSAT Aeronautical mobile satellite service (1).

The indiscriminate use of hand-portable cellular phones within an aircraft can not only be expected to cause significant interference to the ground cellular network, by virtue of the extended radio horizon enjoyed by the aircraft, but can also be a potential safety hazard. The potential safety hazard results from the possible interference with sensitive safety related avionics caused by the cell phone's transmission. This risk is compounded by the fact that the mobile subscriber's handset will almost certainly be commanded to transmit at full power so that an adequate link quality may be provided over the extended range. This concern is reinforced by the UK CAA's current ban on the use of TACS cellphones on passenger aircraft.

The final Acts of the recent ITU World Adminstrative Radio Conference, held in October 1987, which addressed frequency allocations for mobile services permits the use of the Aeronautical Satellite (R) band for public correspondence provided safety related messages take priority. The final Acts also made a new allocation of 1MHz in each direction at 1593MHz and 1625MHz for terrestrial Aeronautical Public Correspondence (APC).

Before any communication system can be designed, it is necessary to have at least a rudimentary estimate of the likely demand, in order to assess the commercial feasibility of the proposed service, and to ensure sufficient capacity may be provided. The study attempted to do this by estimating the geographical distribution of passenger hours per year over Europe and the anticipated GSM hand-portable market sizes and their usage rates. This was carried out for the years 1996 and 2000.

As expected, the geographical distribution of traffic was found to be highly uneven, with the majority of traffic occuring in the triangle bounded by London, Paris and Zurich. Significant capacity must also be provided at major airports, since a substantial proportion of any European flight is spent on the ground. In 1996, it is estimated that the busiest cell would require somewhere between 12 and 30 voice circuits.

The number of voice circuits per aircraft in 1996 ranges between 3 and 8 depending on aircraft size and growth assumptions. The current growth of passenger flights and the pressures on ATC capacity will lead to the use of larger aircraft than those used at present for intra-European flights.

.. SELECTION OF SYSTEM CONFIGURATION

At the highest level, the proposed system must comprise of at least two radio links; one conforming to a sub-set of the GSM air-interface specification in order to create the microcell within the aircraft, and the other to provide a backhaul link between the aircraft and the Aeronautical Base Station (ABS).

The [illegible] directly into the PSTN or, if handover is required, via a switch or network of switches and thence into the PSTN via a gateway associated with each switch. The remainder of this section will concentrate upon the selection of the characteristics of the air-to-ground backhaul link.

The air-ground link can either be a conventional direct terrestrial link requiring a significant number of ground based ABSs, or a single satellite link. The satellite link should make use of existing space segment since the envisaged economics and timescales would preclude the procurement and launch of a dedicated spacecraft. The aeronautical mobile satellite systems under development will make use of INMARSAT-owned satellites and operate in a single channel per carrier (SCPC)/demand assigned frequency division multiple access (DAFDMA) using a 9.6kbps voice codec, 1/2 rate coding and a form of 0-QPSK. The combination of the free space path delay and the processing delay associated with conversion between the GSM and INMARSAT formats will introduce an unacceptable delay for speech traffic.

While the frequency efficiency of the GSM and INMARSAT systems is roughly comparable at the single traffic channel level, current and planned INMARSAT satellites are not able to support frequency reuse within Europe. Thus, the anticipated traffic demand would occupy a substantial proportion of the Aeronautical satellite band which, perhaps, should be reserved for aircraft operating in oceanic or other remote areas where the only terrestrial alternative is HF radio.

For the above reasons, it is clearly preferable to select the direct air-ground option for the backhaul link. In order to minimise the complexity of the avionic equipment, it was concluded that air-ground link format should also be based on that of GSM, however it must be noted that level of coding employed is unnecessary under more benign propagation conditions encountered on the air-ground link.

4. DESCRIPTION OF THE SELECTED SYSTEM CONFIGURATION

4.1 Network Organisation

Figure 1 shows a simplified block schematic of the overall network configuration. The Public Switch Networks (PSTN) within each country are interconnected via an International Switching Centre (ISC). Within each PSTN there may be one or more Public Land Mobile Networks (PLMN), each of which consist of a number of mobile switching centres (MSC). To each MSC is connected a number of Base Stations (BS) which communicate with the mobile stations (MS) in the 900MHz frequency bands. The Aeronautical system consists of a single modified MSC known as an Aeronautical Mobile Switching Centre (AMSC) to which are connected a number of Aeronautical Base Stations (ABS), one per cell. The ABS [illegible] transponder [illegible] aircraft [illegible] between [illegible] the link between the AT and MS operates at 900MHz. Clearly, this link must be fully compatible with its ground counterpart, except for the need to operate at low RF power levels necessary to minimise interference with the ground network.

In this arrangement, handover between the national PLMN and the aeronautical PLMN and cells within the national aeronautical network is facilitated using modified GSM handover procedures. However, handover between adjacent national aeronautical networks will require the use of a complex inter-PLMN handover. This could be simplied if the optional inter-PLMN links between AMSC were implemented.

4.2 Handover

As an aircraft moves from one coverage area to another full handover can be provided, either as an intra- or inter-PLMN handover. The handover process is initiated when the round trip delay indicates that the aircraft is approaching the edge of the cell. The new ABS signal is selected purely on signal strength by the AT.

The control of the handover process is carried out by the AT. To provide a continuous service within the aircraft, two GSM carriers are provided in each aircraft so that during the handover phase one can remain with the old ABS to support existing calls while the other carrier can commence using the new ABS. The MSs will then synchronise with the new carrier and re-register with the new ABS. When the handover phase is complete both carriers may be used for traffic.

4.3 Transmission Delay Compensation

In the GSM TDMA system it is necessary to ensure that bursts originating from various MSs arrive at the BS in a non-overlapping time sequence. In the case of the Aerocellular system the same is true, except that the responsibility for ensuring that this occurs is transferred from the MS to the AT. The delay compensation range must be increased as a consequence of the larger cell size. The delay associated with an ABS-AT range of 400km is 2.3 time slots (i.e. 1.32ms). In the ground system this is performed by adjusting the timing advance of a burst by up to 0.4 time slots. In the case of the aeronautical system a delay must be used in order to provide the required corrections. This implies that the AT adjusts its transmit burst timing so that, as seen by the ABS, the same delay is maintained by all ATs. Burst timing delay errors are measured by the ABS and sent to the appropriate AT on a Stand-Alone Dedicated Control Channel (SDCCH) between the AT and ABS.

4.4 Signalling

Each GSM carrier can support 8 physical channels. Each physical channel can support a Traffic Channel (TCH), and two combinations of Common Control Channels (CCCH) and SDCCHs. Since the projected traffic demand per aircraft could be less than that required to fully load all traffic channels on one carrier, traffic channels in the same TDM must be capable of allocation to different

aircraft. As noted above, a SDCCH is required by each AT to allow the transmission of timing adjustments and handover information. Further SDCCHs are required during the normal call set up process between the MS and the AMSC. It is therefore likely that the 8 physical channels will be allocated as 1 CCCH + 12 SDCCH + 6 TCH. This arrangement has been shown to provide adequate signalling capacity for all envisaged scenarios.

The various signalling procedures used in the basic GSM system can be used with only small modifications, except for the case of AT set up which requires a new procedure and is used when the aircraft registers with the system at the start of a flight.

4.5 Radio Frequency Link

4.5.1 Cell Types. Air-ground propagation is to a first order free space while the aircraft remains in view of the base station, hence the useful range is essentially limited by the distance of the radio horizon. Beyond this limit the path loss increases rapidly (except under anomolous conditions). The height at which the aircraft is flying effectively sets the distance of the radio horizon. Civil airliners remain in controlled airspace at all times. Controlled airspace is subdivided into upper airspace (heights greater than 24,500 ft), airways (nominally 5,000 ft to 24,500 ft) and Terminal Manoeuvring Areas (ground level up to nominally 5,000 ft). To ensure that coverage is provided during all phases of a flight over the geographical region to be served, the three cell types, shown in Table 1, are required.

4.5.2 ABS Antenna. The ABS antenna is generally required to provide omni-directional coverage in the azimuth plane and a cosecant shaped beam in the vertical plane. The cosecant shaping can be maintained up to at least 70 degrees, so minimising the so called zone of silence above the ABS. Additionally, the gain below the horizon must be minimised so that ground reflections are minimised.

To accommodate the requirements of each cell type, two types of antennas are required. For the TMA and En-route (small) cells, an omni-directional antenna with a minimum gain of 5.1dB at 1 degree elevation is recommended. This can be realised using multiple vertical co-linear arrays of about 1.4m in height. For the case of the En-route (large) cells, omni-directional coverage is seldom required as these cells are used over sea paths which in Europe are by definition bounded by land. Hence, it is recommended that a 120 degree azimuth sector is used. A 3.6m high array can be used to provide a minimum gain of 13.7dB at an elevation angle of 0.5 degree.

Clearly, careful siting of base stations is required to ensure that the local topography does not unduly compromise the intended coverage.

4.5.3 Aircraft Antenna. On the grounds of practicality it is conventional to employ a single, nominally vertically polarised quarter wave monopole on the underside of the aircraft. It is unlikely that an antenna used for non-safety services will be optimally located and so depending upon the severity of the aircraft manoeuvres and the aircraft type, substantial performance degradation must be tolerated. Typically, gains of -9.0dBi to -3dBi are exceeded for 90% of orientations.

4.5.4 Propagation. The majority of the work relied upon the generalised statistics presented in CCIR report 424, based on the work of Johnson & Gierhart (2). A number of restrictions of the CCIR report were investigated on specific path profiles using the Longly-Rice model. This confirmed that at medium elevation angles, the CCIR report appeared to be applicable and so after scaling, its data was used to establish link budgets and protection ratios.

The work indicated that a 9 cell repeat pattern is required for the En-route (small) cells and a maximum aircraft height of 50,000 ft. In the interest of spectral efficiency, by limiting the usage of TMA cell to below 10,000 ft, a co-channel ABS to ABS separation

Cell Type	Airspace Region	Cell Radius (km)	Min. alt. at cell boundary (ft)	Max. alt. (ft)	Min. elev. (deg.)
TMA	TMA and airport control zone	50	3,000	10,000	1
En-route small	airway & upper airspace over land	120	7,000	50,000	1
En-route large	upper airspace over sea	300	25,000	50,000	0.5

TABLE 1 - Cell Type Summary

of 400km is possible. En-route (large) cell, co-channel ABS to ABS separations of 820km are needed for aircraft operating at heights of up to 50,000 ft.

The link budgets generated, taking into account the above considerations, show that 10 watts of RF power per carrier is required to provide an adequate service.

4.5.5 Spectrum Requirements. Using the results of the basic propagation work, a cell plan was devised to provide coverage over Western Europe. Such coverage requires the use of 99 en-route (small) and 10 en-route (large) cells. A further 23 TMA cells are required to serve the major European airports. By considering the most densely populated sector of airspace, it was estimated that 34 carriers would be required to serve the median predicted demand for 1996. This could increase to 47 by the year 2000. As each carrier occupies 200kHz, a total of 6.8MHz of spectrum will be required in each direction in 1996. Similarly, 9.4MHz will be required in each direction in the year 2000.

Clearly, a serious shortfall exists between the existing 1MHz in each direction and the estimates presented above. By deviating from the GSM format on the air-ground link, the spectrum requirement can be reduced 3 to 5 fold at the expense of significant increased complexity.

4.6 Aircraft Transponder Implementation

The Aircraft Transponder (AT) is considered to be a key item in the system since, in additon to satisfying the basic functionality and performance requirements, it must be built to meet the appropriate airworthiness requirements while being affordable to the airlines in terms of size, weight and cost of ownership.

The AT is required to act as a two channel bi-directional transponder. The individual transponders must be regenerative since some of the system signalling functions are carried out by the AT, e.g. handover, transmission delay compensation. Doppler compensation is also required to be carried out by the AT.

One possible block diagram of an AT is shown in Figure 2. Signals at 1625.5MHz are received by a common antenna mounted on the underside of the aircraft. A single coaxial cable connects the antenna to the AT located in the avionics bay. The diplexer is required to allow simultaneous transmission and reception. The receive signals are directed towards the Low Noise Amplifier (LNA) prior to down conversion to about 900MHz using a Local Oscillator (LO) at approximately 2.5GHz. The output of the down converter is then applied to each of the two ground-to-aircraft transponder blocks. It is proposed that, where possible, the transponder will make use of existing base station/mobile subscriber equipment in the interests of economy. Signalling information must be decoded and passed to the controller which is responsible for protocol execution and time delay compensation. The output of the transponders, at 900MHz, are combined and amplified to provide of the order of 13dBm per carrier. A conventional TACS type of diplexer allows the use of a single antenna or leaky feeder for the inside aircraft link.

The return direction is largely the reverse of the ground/aircraft direction described above, except that signalling messages generated by the controller are inserted into the appropriate timing slot, and a variable delay element is placed in the baseband link between the demodulator and remodulator to facilitate time delay compensation. The High Power Amplifer (HPA) is required to provide two 10 watt with carriers at 1595MHz with an acceptable level of intermodulation products. It is assumed that the HPA design could be based on that used by the INMARSAT system. The transmit signals are applied to the antenna via the diplexer and antenna feeder cable.

It is estimated that all of the transponder electronics, with the exception of the HPA, can be accommodated in a single 6 MCU ARINC 600 (192mm wide) case. The HPA can be accommodated in an 8 MCU (256mm wide) case. The L-band antenna can be housed in a blade-shaped radome with a height of 65mm and a length of 120mm.

5. CONCLUSIONS

This paper has described a system which, with minimal development, is capable of providing a GSM environment within suitably equipped aircraft operating over Europe. The system is capable of supporting the majority of the services provided by the ground based GSM network. While the system described makes maximum use of the technology currently being developed for the ground based GSM system, a major disadvantage is the relatively low spectral efficiency that results. Alternative voice coding, FEC coding and modulation schemes have been identified which can improve the spectral efficiency significantly at the expense of substantially increased development and technical risk.

6. ACKNOWLEDGEMENT

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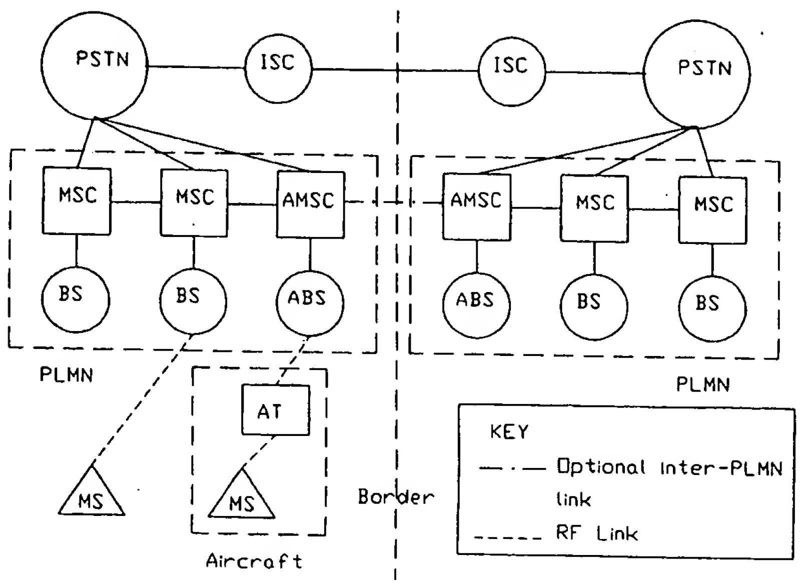

Figure 1 Aerocellular System in National PLMNs

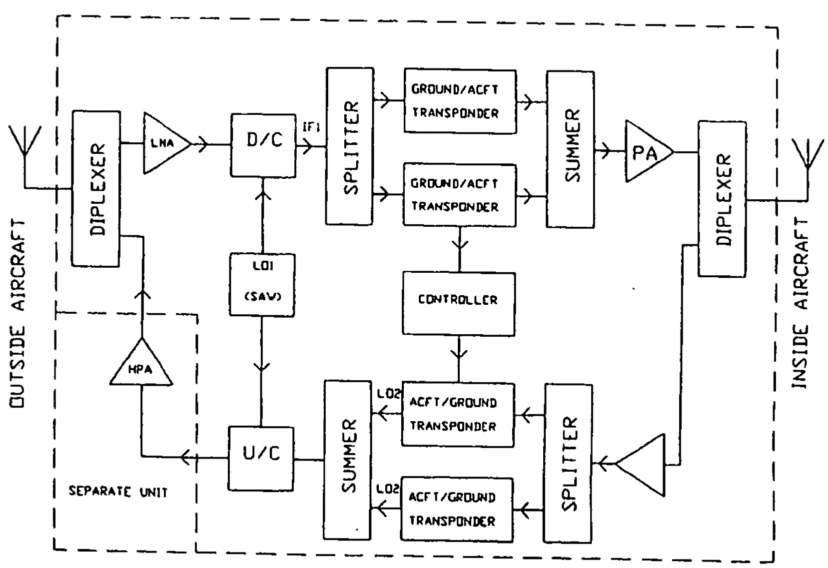

Figure 2 Block Diagram of the Aeronautical Transponder